Improved Satellite-Monitored Radio Tags for Large Whales: Dependable ARGOS Location-Only Tags and a GPS-Linked ARGOS Tag Reveal 3-Dimensional Body-Orientation and Surface Movements

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LONG-TERM GOALS

The goal of this project is to develop reliable sensing and monitoring technologies to identify the seasonal distributions of large whales, their underwater behavior, their ecological relationships, and ultimately their behavioral responses to man-made sounds. This involves both attachment and electronic developments. Two different semi-implantable satellite-monitored radio tag technologies will be further developed for whales: 1) a programmable, location-only (LO) Argos tag using contemporary technology will be available and be adaptable to testing a variety of attachments. Ultimately, it will be suitable for many scientific users to track local and seasonal movements of medium to large whales over varying time scales (months to a year); and 2) an improved recoverable GPS/TDR tag will include 3-axis accelerometer and compass sensors to document the detailed dive behaviors and foraging ecology of large whales over scales of weeks to months and will be capable of carrying additional acoustic recording devices useful in evaluating future noise response experiments.

We made progress this year in tag attachments, development and testing of both tag-types, analytical methodologies and assessing wound healing. We were able to use other (non-ONR funded) projects to defray field costs for testing the ONR-funded developments. This work is reported below separated into objectives and approach, work completed, and results that demonstrate a variety of accomplishments.

OBJECTIVES and APPROACH

<u>Location-only tags</u>

The ONR-funded tags have been used on a variety of projects: western gray whales in Russia, Pacific Coast Feeding Group (PCFG) gray whales, and sperm whales in the Gulf of Mexico associated with the Deepwater Horizon Oil Spill. These deployments allow us to test the functionality of the Spot-5 tag and compare it to the old ST-15 style in order to identify potential areas for improvement.

A continuing part of this ONR project involves the photo follow-up of tags to examine wound healing, part of which is also the subject of collaboration with Cascadia Research as part of a NOPP project.

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Photographs of tag sites are taken during tag deployment and any time a tagged whale is re-sighted during subsequent trips. Results will be presented to, and reviewed by, the IWC Scientific Committee for recommendations on additional whale research and tag development work. Some of this research will be presented at specific science-based meetings to improve whale management and ONR's review of their investments in this field.

We are also continuing to develop new attachment methods through a collaboration with the Oregon State University Mechanical Engineering department. Undergraduates, supervised by graduate students and faculty mentor John Parmiagani, are developing ballistic gels and foams to mimick the different layers of skin, blubber, fascia, and muscle in a whale. With the gel and/or foam in place, they will then test different attachment methods and materials in a laboratory setting to identify and correct weak points.

<u>Advanced Dive-Behavior Tag</u>

The GPS/TDR tag (initially funded by JIP, MMS, and ONR) will be further developed to provide an accurate, long duration, depiction of underwater dive behavior and especially to examine sperm whale foraging behavior. The data will be downloaded from recovered tags to evaluate complex foraging behaviors. The addition of an acoustic dosimeter remains an un-funded, but long-term goal that would help interpret whale responses recorded by the tags during future controlled-exposure experiments (CEE) or behavioral response (BRS) studies. The existing GPS/TDR tag will be field tested on whales with the 3-axis accelerometers and magnetometers before any attempt at integration with an acoustic dosimeter.

Eleven GPS/TDR tags containing three axis accelerometers were deployed on sperm whales in the Gulf of Mexico in July/Aug 2011. Following the results of that field work we collaborated with Wildlife Computers (WC) to re-design the entire tag. FastLoc version 3 technology was added, providing a 90% improvement in power consumption over the previous version. Magnetometers were also added to the tag, allowing the whale's heading to be calculated, allowing us to re-construct its movements during a dive. Two additional release pins were added allowing the tag to be re-used up to three times before replacing the batteries. Numerous other changes were made to the design, bringing it up to WC's production standards. Nine of the re-designed GPS/TDR tags were deployed on sperm whales in the Gulf of Mexico in July 2013.

WORK COMPLETED

<u>Location only tags</u>

WC Spot-5 tags were attached to 7 western gray whales in 2010 and 2011 (funded by the International Whaling Commission) to determine their migration routes, on 20 sperm whales in 2010 - 2013 (funded by BP and NOAA-NRDA) to follow-up on the consequences of the Deepwater Horizon (DWH) oil spill and to compare their operation with older-style Telonics ST-15 tags (applied during 2001-2005 in the SWSS program and in 2010 during the DWH event), and on 33 PCFG gray whales in 2009, 2012 and 2013 (funded by the navy fleet) to assess the use of navy training ranges by marine mammals. At no direct cost to this ONR project, three undergraduate engineering students have finished testing ballistic gel to simulate whale skin/blubber/muscle, but these did not do a good job. However, a variety of stiffer closed-cell foams worked quite well, and have been useful in testing various tag attachments.

Advanced Dive-Behavior Tag

Wildlife Computers incorporated a 3-axis accelerometer into the GPS/TDR tag (also known as PATF or Mk-10). As a brief review, our previous experience developing this tag began with 2007 deployments when the corrodible wire holding the tag to the attachment sheath sheared causing a premature release of the tag. In 2008, WC modified the design to a heavier wire and we provided three large studs in the attachment sheath that penetrated into three voids in the tag float that prevented the tag from rotating and shearing the wire. However, in 2008 the manufacturer did not draw a vacuum on the casting matrix and small bubbles in the casting collapsed under the pressure of sperm whale dives to short out the electronics. Eleven tags were deployed in 2012 on sperm whales in the GoM (with ship logistics paid by the NRDA follow-up to the Deepwater Horizon/BP oil spill) after adding three axis accelerometers to the design. The tag was re-designed as described above and nine of the re-designed tags were deployed on sperm whales in the Gulf of Mexico in 2013.

RESULTS

Location only tags - gray whales

The 33 spot-5 tags applied to gray whales in 2009 - 2012 transmitted data for an average of 105 days (max =409 days, average = 120 days for only 3 battery Spot 5) compared to the 20 Telonics ST-15 tags deployed in 2005 and 2012 which transmitted for an average of 103 days (max = 321 days). All six Spot-5 tags deployed in Oct 2013 are still transmitting so they are not included in the duration summary. Short summaries of a variety of projects using the location only tags are presented below.

Western gray whale (WGW) migration routes

A 13-year old male WGW named Flex was tagged on 4 Oct 2010 off Sakhalin Island, Russia, and was tracked for 128 days. After 69 days off Sakhalin Island, it migrated across the Bering Sea, the Gulf of Alaska and along the Pacific NW until it reached the central Oregon coast on 9 February 2011. In August 2011, Flex was re-sighted during additional tagging operations off of Sakhalin Island. He was in good body condition, confirming there were not unexpected adverse affects and that he had made a complete round trip to and from the eastern North Pacific. As a result of this migration, Weller et al. (2012) circulated photos to many gray whale scientists for catalog comparison. They determined that Flex and many other WGWs have previously visited the eastern North Pacific.

The 2011 tagging of 6 WGWs off Sakhalin resulted in two more significant tracks away from the island. Two females were tracked across the Bering Sea. One tag (on Agent) quit half way across the Gulf of Alaska, while the other (on Varvara) went all the way to nearly the tip of Baja and back to Sakhalin. She covered 23,000 km in 5.5 months and visited every known eastern North Pacific gray whale reproductive area. This is the world record migration for any mammal (Figure 1). The tag finally stopped transmitting after 408 days. It has provided the first documented complete migration cycle for WGWs and, while it was at the summer foraging area, it recorded the smallest calculated home range and core area for any baleen whale we have ever tracked for more than 5 months.

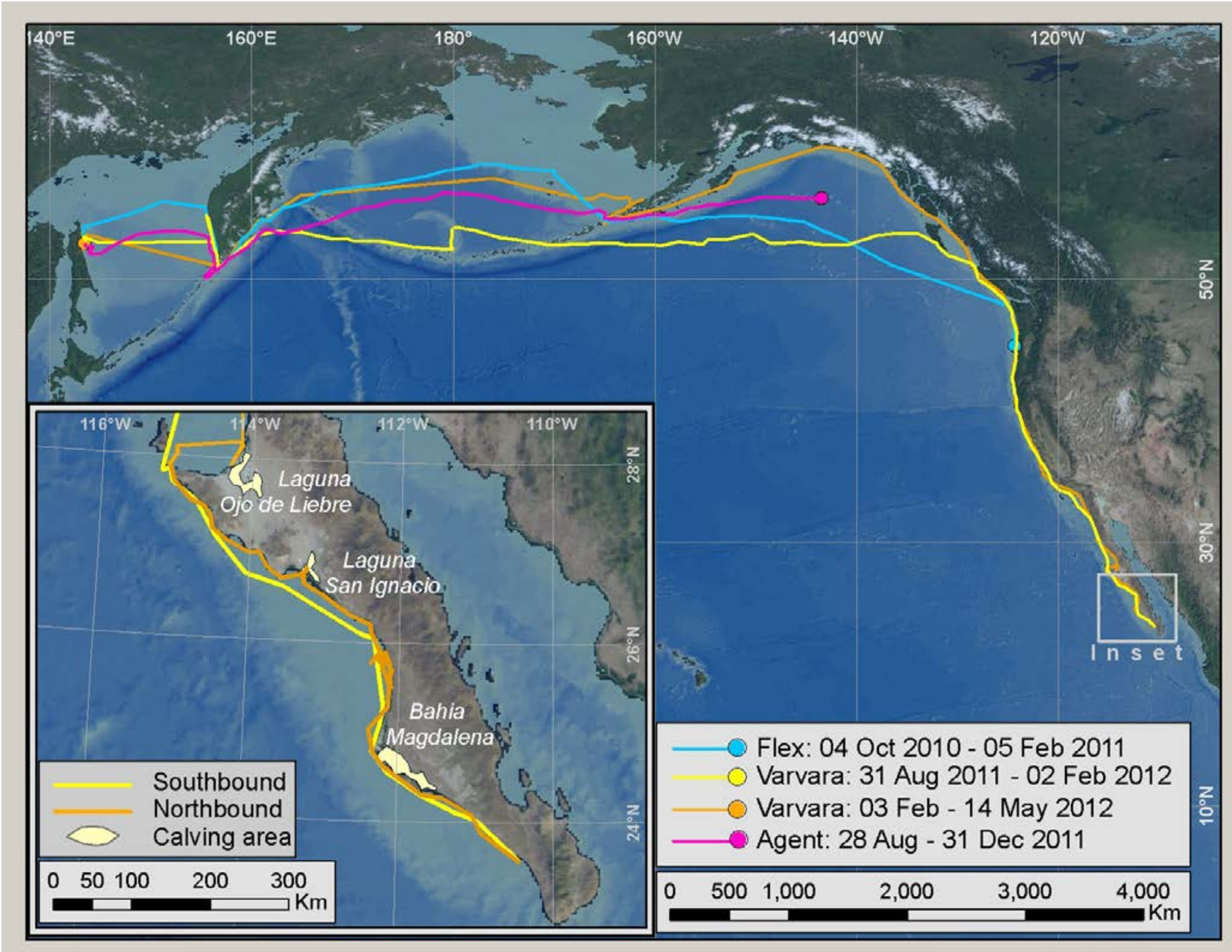


Figure 1. The tracks of three western gray whales tagged in Russia during 2010 and 2011 that migrated from Sakhalin Island to the eastern North Pacific.

PCFG gray whale habitat and migration

Satellite tags were attached to gray whales from the pacific coast feeding group (PCFG) during fall 2009, 2012 and 2013 (tags deployed too late for data to be presented here). Some tags were deployed near Newport, OR, but by mid-October in all years, very few whales were left in the area and the majority of the tags were deployed near Crescent City, CA. All whales were identified as PCFG whales from Photo ID. Southward migration generally began in late November/ early December, though it occurred as late as mid-February, and, in one case, did not occur at all with the whale remaining near Crescent City, CA throughout the winter (Figure 2). Twelve tags functioned long enough to capture southward migration. All but one of those whales migrated to the area near Laguna Ojo de Liebre Baja Mexico, with the other travelling to the waters of Bahia Magdalena, Baja Mexico. In 2009 the whales remained near the lagoon for approximately 21 d, but the residence time in 2012 was much more variable with one female whale remaining there for almost 2.5 months, probably as a result of calving. We tried to relocate the whale as it passed the Northwest en route to Icy Bay, but bad weather kept us from being successful. Northward migration was captured for eight whales that all migrated to areas of higher latitude than they occupied in the fall. Most whales arrived off the central and southern Washington coast from late February to early April, though two different whales (one each in 2009 and 2012) continued north all the way to Icy Bay, Alaska.

The tracking data acquired here provides a number of insights into the year-round distribution of PCFG gray whales. The whales arrived in the waters off Oregon and Washington in early spring and, while they visit a number of locations, they generally occupy the more northerly portion of their range from spring into the summer, spending more time further south off Oregon later in the summer. The two whales that travelled up to Icy Bay, Alaska show that the PCFG range extends much further north than previously thought. Movements by the whales almost certainly represent exploration for areas with high prey concentrations, so the southward shift in area use suggests that prey is more abundant in the northern portion of the range during the spring and early summer, and that abundance shifts south later in the year. St. George Reef near Crescent City was an area of very high gray whale concentration late in the fall in both years suggesting it maintains a high prey concentration much later than other parts of the PCFG range and appears to be used as a "staging area" (last stop) for food by many whales prior to the southward migration when fasting is considered normal. The almost exclusive use of the Laguna Ojo de Liebre area by tagged PCFG whales was unexpected, although it is the most used of the three breeding and calving lagoons. The regional concentration may help create opportunity for genetic differentiation of PCFG whales from other eastern gray whales.

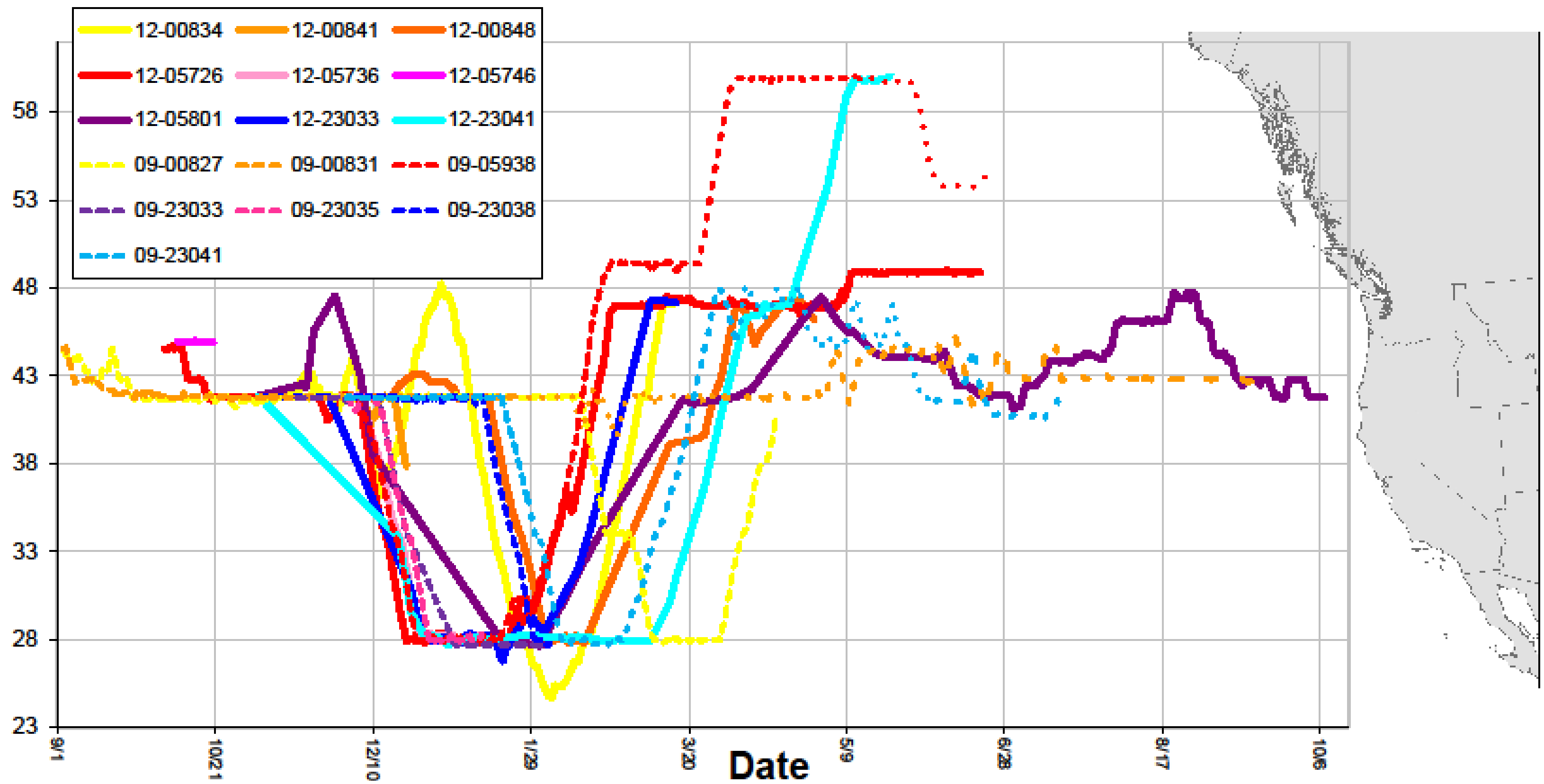


Figure 2: The latitude of Pacific Coast Feeding Group (PCFG) gray whale satellite locations plotted by date (month and day). The figure shows two years of satellite tracking data (2009 and 2012) for whales tagged off Newport, OR and Crescent City, CA. The first two digits in the legend represent the year the whale was tagged and the last digits are the individual whales number.

Location only tags - *sperm whales*
The seven spot-5 tags applied to sperm whales in July 2011 and 2012 transmitted data for an average of 174 days (max =409 days) compared to the 33 Telonics ST-15 tags deployed in 2010-2011 which transmitted for an average of 129 days (max = 295 days, although during the SWSS-era the averages were higher with a max = 607 days). Short summaries of some results from the sperm whale tagging are presented below.

Comparison of sperm whale home range size between pre– and post–Deepwater Horizon Oil Spill
The male sperm whales tagged during the SWSS study (2001–2005) inhabited a significantly larger portion of the GOM and displayed a lack of site fidelity when compared to females and males tagged after the Deepwater Horizon Oil Spill. The average male home range size significantly decreased from SWSS years to 2010/11 (Figure 3). The average female home range also decreased in size between SWSS to 2010/11; however, the decrease was not statistically significant. The observed differences between the sexes in the SWSS data were expected based on current knowledge of sperm whale social structure that suggests adult males roam more widely. Therefore, the much smaller home ranges of the 2010/11 males were unexpected, though it is possible these results are an anomaly resulting from the small sample size. A much greater sample size of males is needed to account for this large difference between males tracked during SWSS and 2010-2011. It is possible that prey availability and density patterns were quite different between pre– and post–oil spill years. Increases in prey concentration might account for decreases in home range area. Results from plankton studies in the GOM may provide clues to help explain these differences.

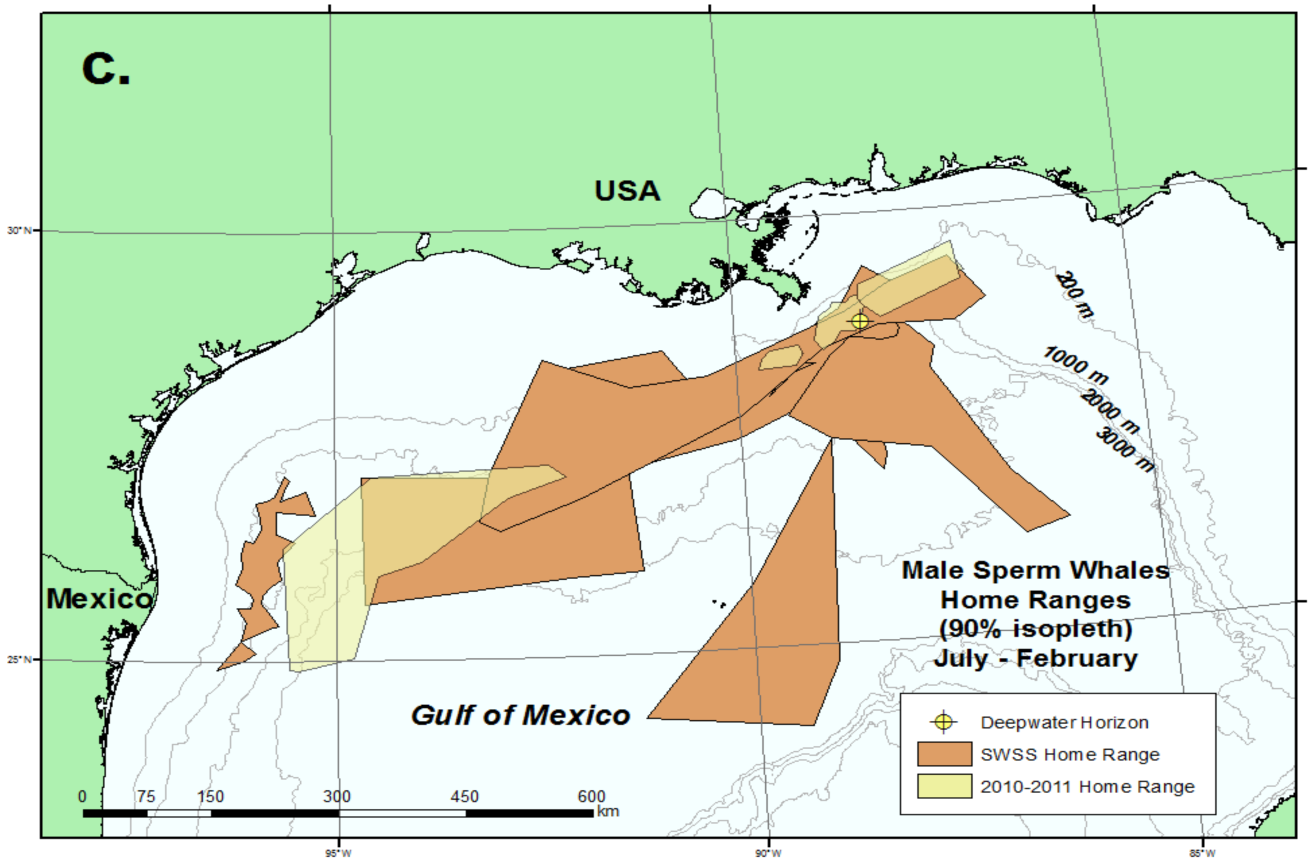


Figure 3: Home Ranges (90% isopleth) computed from sperm whale state-space modeled locations for tags transmitting 120+ days after tag deployment through March 1 of the next year.

A subgroup of seven 2011 females and one from 2003 were tagged in deeper waters (>1200 m) than all other females tagged off of Louisiana. Their tracks were also in deeper waters than all other females and they may represent a different subpopulation (figure 4). There was an oblong-shaped 4,000 sq. km area between the deep females and those on the upper continental slope, which was used very little in 2011 and includes the MC252 Oil Spill well site. The gap between deep and shallow water whales is a region that requires further study. While it may be due to chance, or different habitat preferences between the two groups of females, the inclusion of the MC252 Oil Spill well site in the unused area raises the possibility that there may be lingering effects from the spill, particularly as the two groups' ranges appear to abut one another to the west.

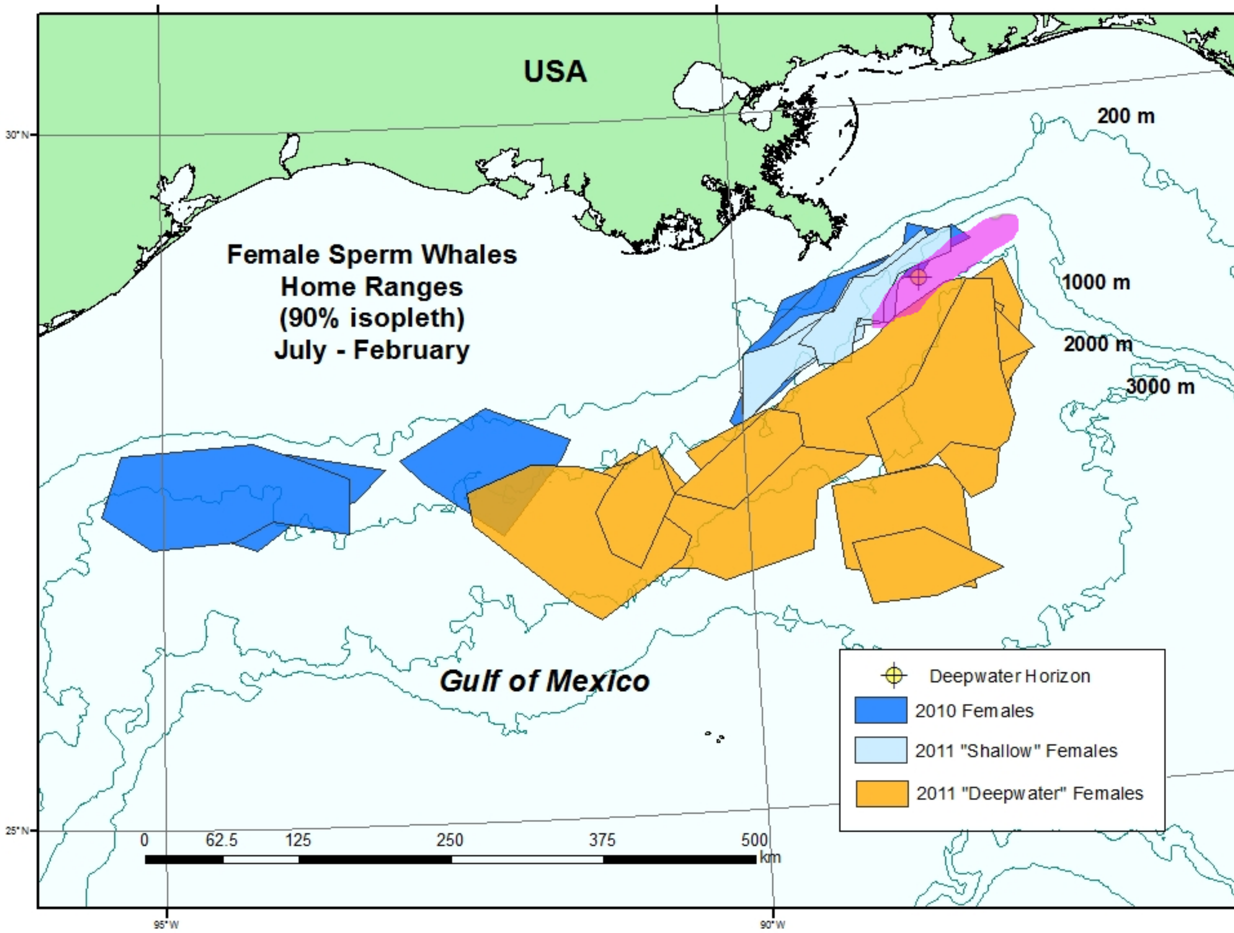


Figure 4: Female sperm whale home ranges (90% isopleth) computed from state-space modeled locations for tags transmitting at least 120 days after tag deployment through March 1 of the next year. 2011 deployed tags are separated into females tagged in waters >1200 m ("Deepwater" females) and those in shallower waters ("Shallow" Females).

Changes in sperm whale home ranges with time

This analysis was performed to better understand the length of time needed to provide a valid estimate of a sperm whale's home range. Because tag longevity can vary tremendously, it is important to determine a minimum time series needed to maximize the number of individuals included in a home range analysis.

Tracks lasting a minimum of 90 days from sperm whales tagged in the Gulf of Mexico from 2001–2005 (SWSS data), and 2010-2012 (Deepwater Horizon Study) were used to compute home range areas. We are defining home range as the 90% isopleth using the LoCoH algorithm (Getz *et al*. 2007). Argos locations were processed using a state-space model (SSM) developed by Jonsen *et al.* (2005) to provide one location per day. If there were gaps in Argos locations >10 days, the SSM locations for

those gaps were not included as they were essentially straight line interpolations between SSM data points computed from Argos.

A minimum of 60 locations were used to compute the first home range area estimate and successive estimates were computed by iteratively increasing an additional 30 data points until all data points were included. Home range areas were plotted for each individual vs the number of days from tagging (figure 5 and 6). Because gaps in Argos locations (>10d) were eliminated, the number of data points did not always correspond to the number of days from tagging.

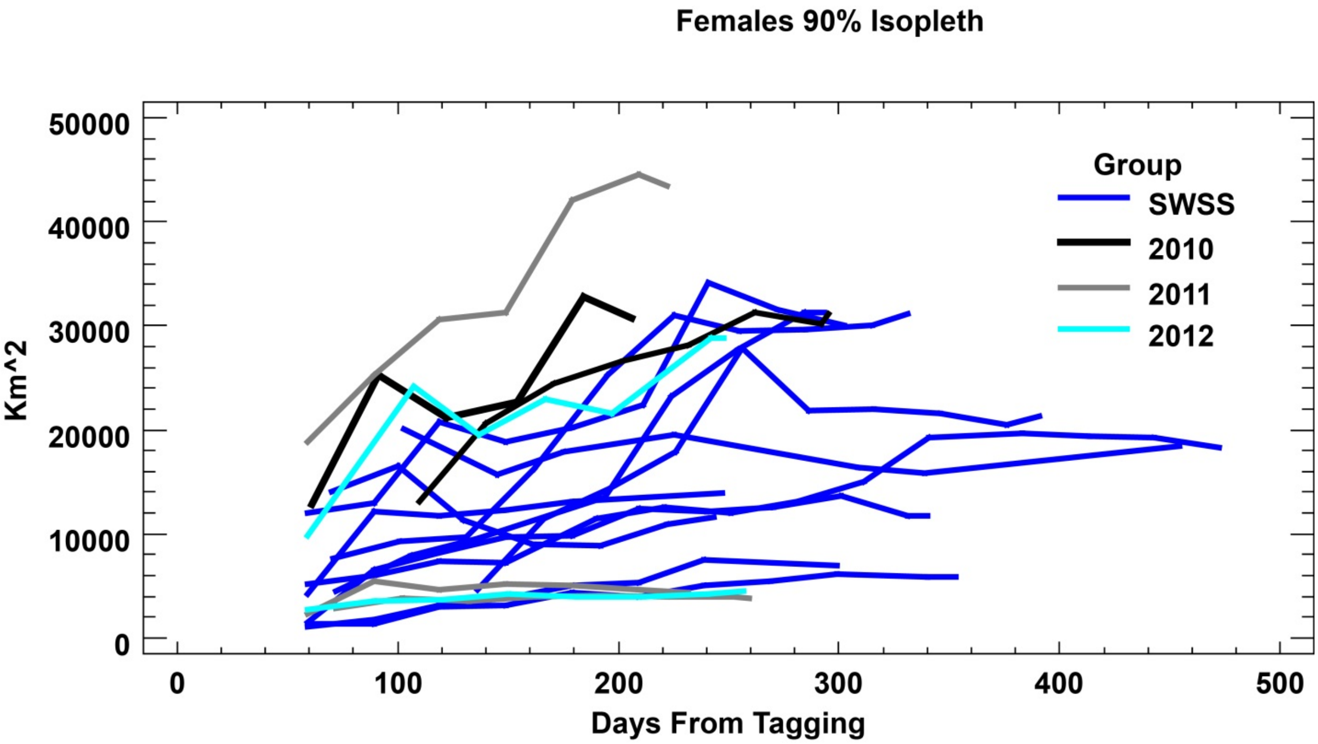


Figure 5. Plot of individual female sperm whale home range areas (90% isopleth) by iteratively increasing the number of data points in increments of 30. There are 11 SWSS, two 2010, three 2011, and two 2012 females.

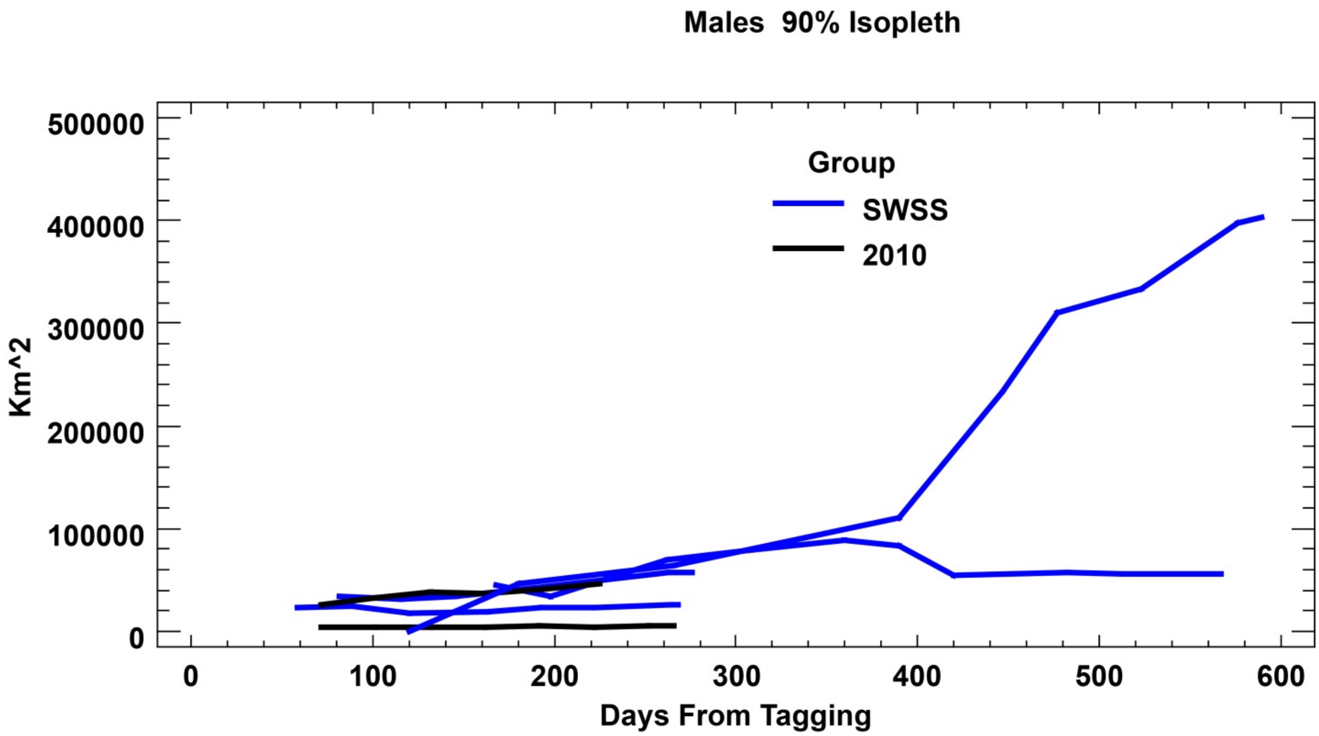


Figure 6. Plot of individual male sperm whale home range areas (90% isopleth) by iteratively increasing the number of data points in increments of 30. There are four SWSS and two 2010 males.

Individual variability for both males and females indicate it would be difficult to be confident that home range estimates had stabilized within three months of tagging. Several individuals had still increasing values after 200+ days. Visually, there appears to be no obvious difference between SWSS years and 2010-2012 though sample sizes are extremely small.

<u>Advanced Dive Behavior Tag</u>

In 2011 we deployed 11 Wildlife Computers PATF tags equipped to collect data on sperm whale dive depths and body orientation (using 3-axis accelerometers) at 1 s intervals, as well as GPS quality locations. While dive summary messages were sent via Argos, the entire data archive was stored onboard the tag and could only be accessed after the tag released from the whale and was recovered. The tags transmitted for an average of 26 days and sent back an average of 70% of all the archived histogram summaries of depths and durations of dives for the summary periods. However, due to a failure of the tag's release software only one tag was recovered. It contained a continuous 42 day record of 744 dives > 350 m depth, 855 GPS-quality locations and information on rapid changes in body orientation (lunges; calculated from the accelerometers) during dives that likely indicate prey capture attempts. A map showing the lunges/dive on the whale's track (from the GPS locations, Figure 7) suggests the whale searched for prey in a large, but patchy environment, as dives of similar dive depths and durations with many lunge events (likely high prey density) were close to dives with few lunge events.

In 2013 magnetometers were added to PATF tags so that the underwater movements of the whales could be reconstructed. Of the nine tags deployed on sperm whales, one tag never transmitted after

deployment, two tags functioned normally but never released from their housings and were not recovered, and the other six tags released as scheduled, five of which were recovered. The sixth tag traveled out into the central Gulf beyond recovery range following release and was thus lost. The tags were programmed for release at the end of the tagging season and lasted an average of 15 d. Excluding two poorly deployed tags, the average was 19.5 d, and four were still attached to whales when they reached their programmed release date. Data archives from the five recovered tags provided an enormous amount of data similar to the recovered tag from 2011 plus magnetometer data for determination of body orientation. Rapid changes in body orientation (lunges) were apparent in the dive data from all tags and varied substantially from dive to dive. Some whales were documented making no dives deeper than 20 m for 2–4 hrs at various times of the day, possibly indicating resting or surface-oriented socializing behavior. The external temperature recorded by the tag can be used to identify the mixed layer or thermocline depth to see if the whales may be foraging near oceanographic features like warm core rings, but this analysis has not been done yet. The addition of magnetometers to the tags allow for reconstructing the movements of the whale while underwater and identification of interesting in-dive behaviors like a tight triple spiral (Figure 8 a) near the bottom at 1300 m or continuous barrel rolls (Figure 8 b). Additional analyses of lunge data connected to the reconstructed dives will likely identify behaviors representative of searching or foraging behavior by the whales. The duration of collecting such varied data by these tags is unprecedented, allowing identification of fine-scale behaviors of sperm whales, habitat characteristics important to foraging attempts, and studying the variability within and between whales using the same region (consistency issues) over periods of weeks to months.

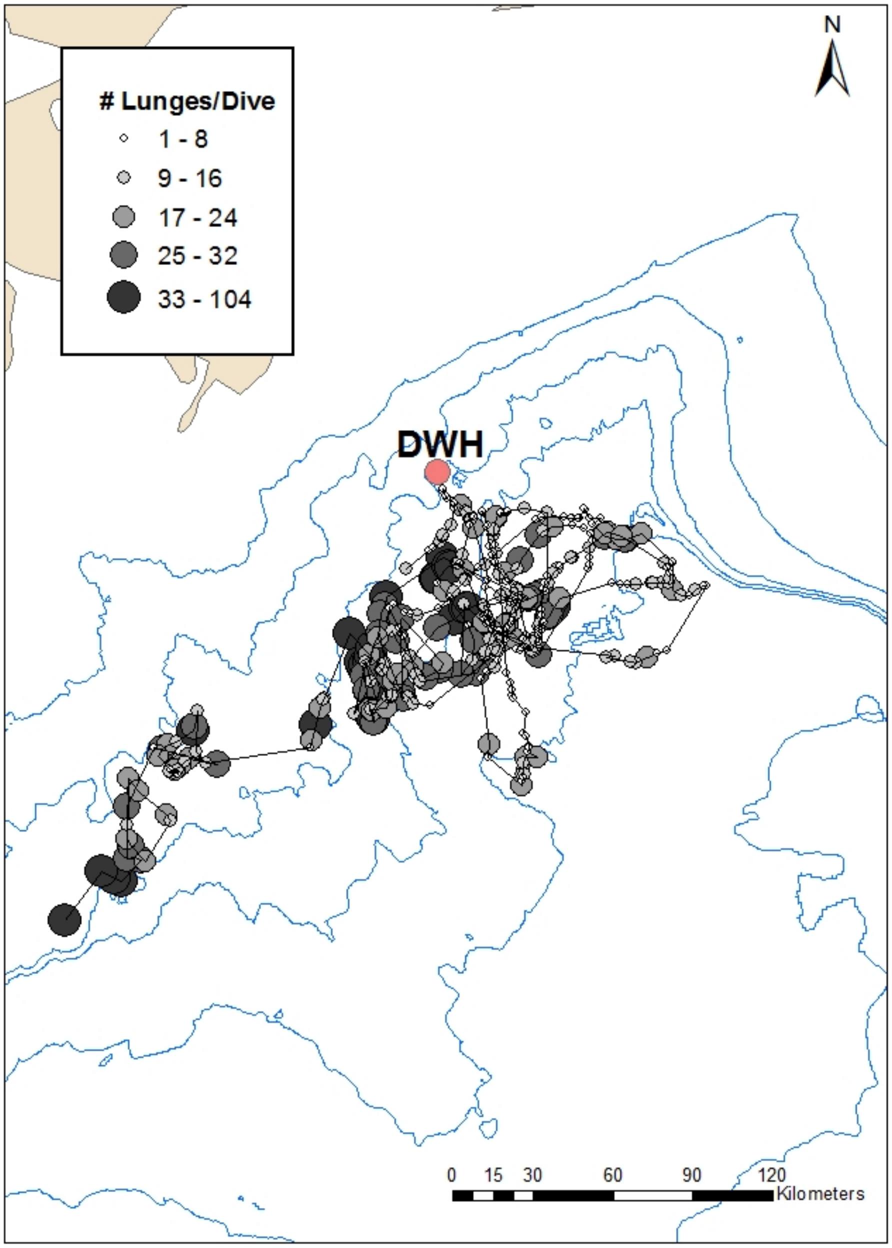


Figure 7: Map of GPS locations recorded by a satellite-monitored TDR tag attached to a sperm whale in the Gulf of Mexico that traveled >2300 km. The size and shading of the circles relate to the number of lunge events that occurred during the bottom phase of individual dives > 350 m at each position. Darker colors and larger circles equate to more lunge events per dive. The red circle labeled DWH represents the site of the Deepwater Horizon oil spill. Note the considerable regional

variability, which likely explains the whale covering such a large area in search of small, but dense prey patches.

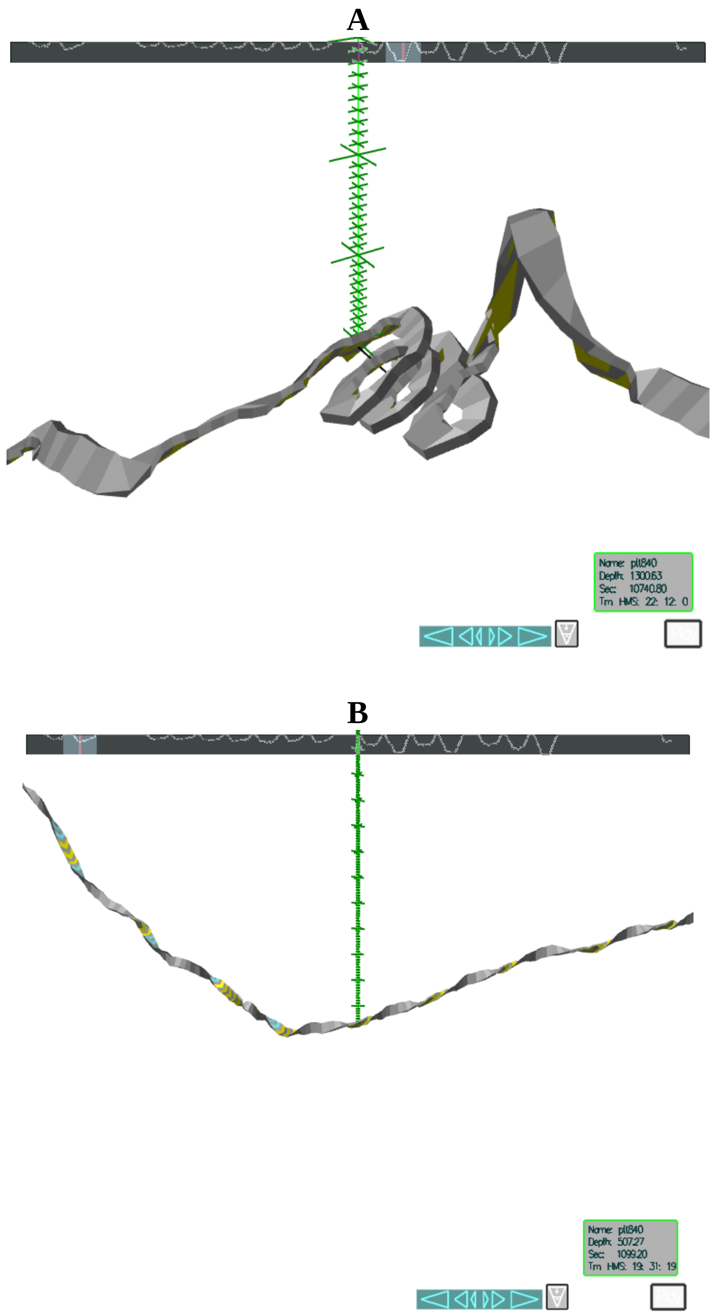


Figure 8: A portion of a sperm whale dive track reconstructed from 3-axis accelerometer and magnetometer data showing A: a triple loop made by the whale at 1300 m depth, and B: a series of barrel rolls made by the whale at approximately 500 m depth during a dive, perhaps allowing search imagery like an oscillating locomotive headlight to "illuminate"/find prey in a larger area than just straight ahead.

Analysis of Kalman Filter Processing of Argos Data

In March 2011, Service Argos (CLS) started offering locations calculated using a Kalman filter (KF) as a substitute to the non-linear Least-Squares (LS) technique. CLS recalculated several MMI tracks providing KF locations for comparison with the LS data. Locations from two sperm whales tagged with MK-10 GPS tags (04173 and 04177) and one Gray whale with a SPOT5 tag (00846) were used. Both sperm whale tracks were processed using the default Argos maximum speed of 10 m/s and one track (04173) was also processed using a more realistic upper bound speed of 1.8 m/s. The gray whale track was processed using both the default Argos speed of 10 m/s and a more realistic upper bound speed of 3.6 m/s.

There were differences in the total numbers of locations and numbers in each Location Class (LC) between KF and LS tracks and between KF tracks with different maximum speeds. In all cases, KF processing produced many more locations mostly due to LCB locations computed from just one message (LCB(1)), more LC2 and LC3s, and fewer LCZs than LS processing. Different maximum speeds for KF processing produced different geographic positions and, sometimes, LCs.

The sperm whale tags had sufficient numbers of Argos locations close enough in time to a GPS location (<10 min. apart) to compare KF and LS accuracies by location class. There were no significant differences (ANOVA) in accuracy between processing types except for LCBs (p<.0001; Figure 9.)

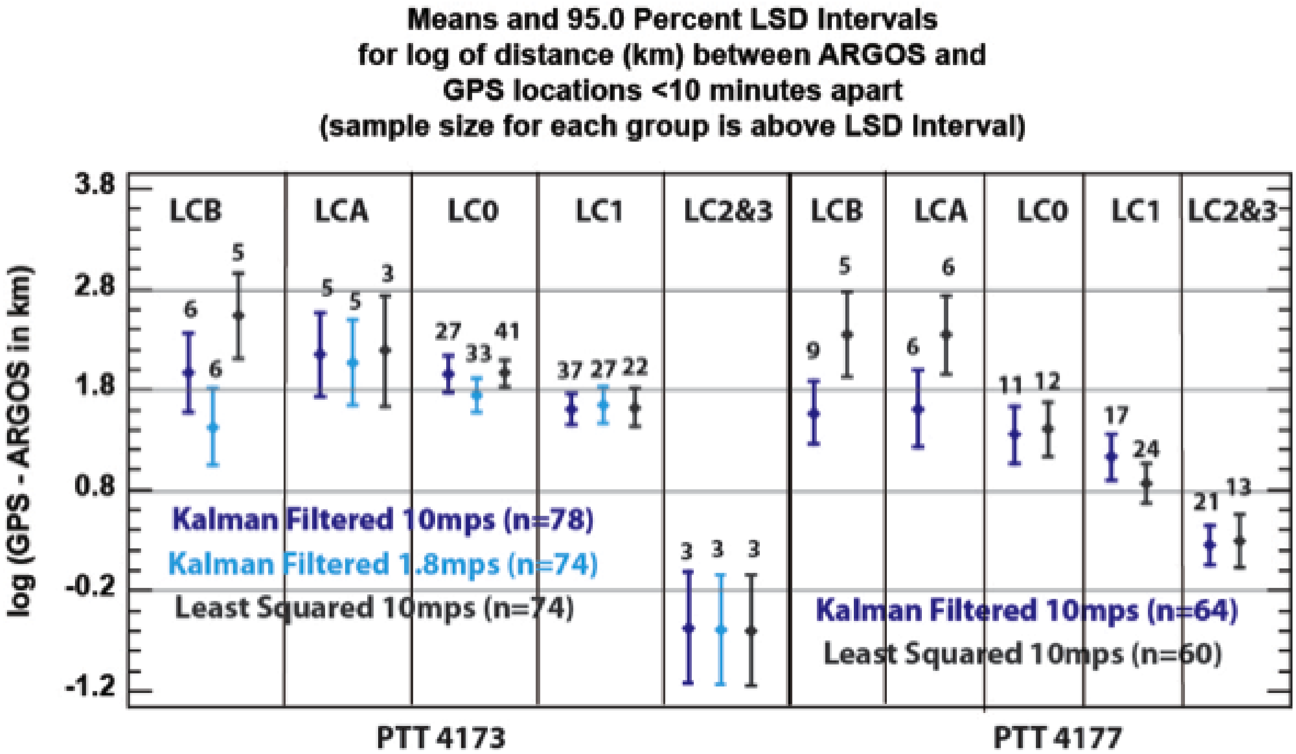


Figure 9. Plot of the mean (circle at middle of vertical line) and 95th percent least significant difference (LSD) interval (vertical line) for the log of the distance (km) between Argos and GPS locations less than 10 minutes apart by PTT, processing type (color coded) and Location Class (LC). LCZ locations were not included in the analysis and, due to low sample size, LC3s were combined with LC2s (LC2&3).

Though PTT-00846 did not have GPS to benchmark actual locations, visual comparisons of tracklines showed many more "excursions" (presumably due to ARGOS errors) in the LS processing. Figure 10 exemplifies this most dramatically off Sakhalin Island where it can be assumed that the whale would remain close to shore.

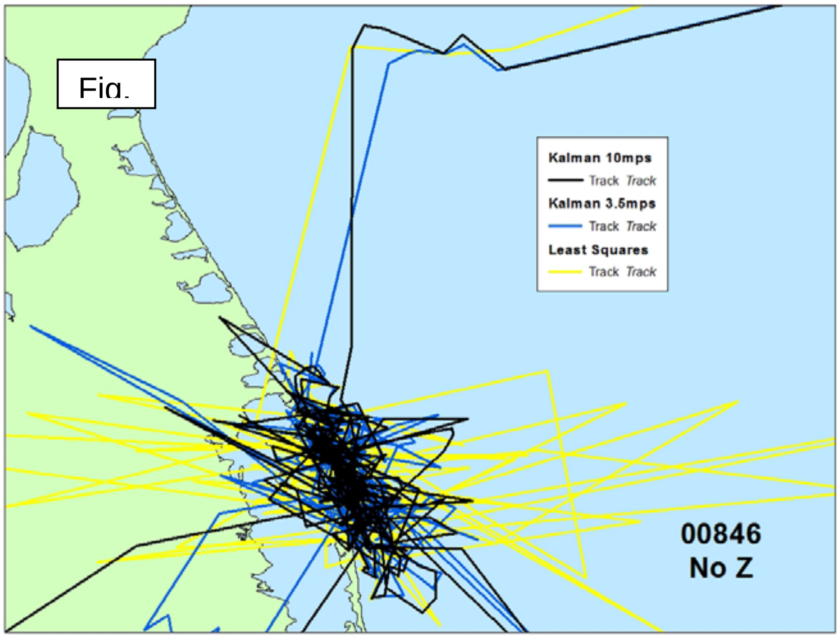


Figure10: Tracks for PTT-00846 using Kalman Filter processing with 10 m/s (Kalman 10mps) or 3.5 m/s (Kalman 3.5mps) maximum speeds and Least Squares processing off Sakhalan Island, Russia. Location Class Z locations were not included.

Recommendations

The only statistically significant evidence to choose one processing technique over another was in the case of LCBs where KF processing was closer to GPS locations than LS (Fig. 9). Qualitative analysis (Fig. 10) also supports the use of KF processing by illuminating the greater number and extent of "excursions" in LS locations. The recommendation is to use KF processing as it provides additional locations and more locations of higher LC's. A more difficult question is whether to use the default or "reasonable" maximum speeds. Since there are a greater number of higher quality locations using the default 10m/s, it makes sense to stay with the default value until further analyses can be performed.

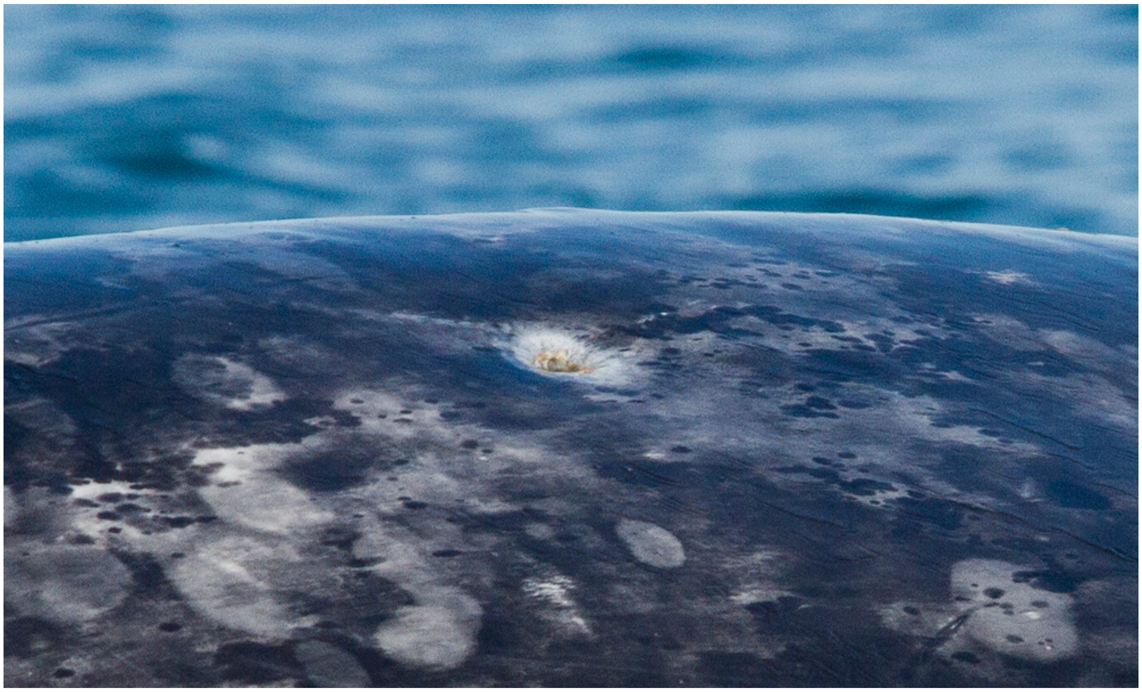
Wound healing

Extended resights of 4 populations of tagged whales have given us a chance to observe tag site healing over time. Tagged individuals from two populations of sperm whales, one in the Gulf of California and the other in the Gulf of Mexico have been resighted up to 22 months (GoC) and 131 (GoM) months after tagging. Tagged gray whales from the Pacific Coast Feeding Group have been resighted up to 49 months after they were tagged. Tagged gray whales from the Western Pacific population have been resighted up to 11 months after tagging.

In gray whales the most common result of tagging is a divot that ranges in size from 4-15 cm in diameter. In many of these divots there was a loss of pigmentation and a colonization by cyamids. In sperm whales the divots tended to be smaller at 4-8 cm diameter with few changes in pigmentation. Over time the size of the divots on both species tended to shrink and some re-pigmentation occurred on gray whales. In some cases, swelling has been seen around the tag sites, either localized (extending 3-15 cm around the tag) or regional (30-60 cm around the tag), but most of these have shown considerable

improvement or complete healing over time. No resighted whales were emaciated or exhibited other visible conditions suggesting adverse effects from tagging.

Experienced veterinarians and the IWC Scientific Committee examined follow-up photos of tags to evaluate wound healing. They concluded only expected scarring and divot formation were seen and that these did not pose any significant hazard to whales, even for the fetus of pregnant western female gray whales if they were tagged.



Gray whale with scar 46 months after it was tagged.

Sperm whale with scar 12 months after it was tagged.

Photo Summary for Gulf of Mexico Sperm Whales Tagging 2013
50 sperm whales were seen well enough to assign an ID. Most IDs are from dorsal fins, but also a high number of flukes were photographed this year. 32 out of the 50 IDs have a corresponding fluke shot including 9 of the tagged whales.

Nine whales that had been tagged in previous years were resighted. Of those, 6 were retagged. Photo IDs made it possible to determine that the first whale tagged this season lost its GPS tag and to retag it with another GPS tag later.

Two whales where seen with remnants of old tags. One whale tagged in 2011 was seen with the same remnant of a tag as in 2012 when it was retagged for the third time. It was not retagged this year. The second whale was initially tagged in 2010 and retagged this year.

Two whales were seen with possible tag scars that have not yet been previously identified (IDed). Also three of the whales with scars that can be IDed to past years have a second or third scar that looks like it is also from a tag, but no connection to a previously tagged whale has been made for those scars. We are aware that other researchers have been taking biopsies in this region for at least the last 4 years and wonder if these are not scars from that sampling.

In two cases whales that had had a dorsal fin callous in past years were seen this year without the callous indicating that the presence of a callous often used to identify females in the past is not permanent, and therefore inappropriate as a sexual identification feature.

One whale was seen that was severely emaciated. It had many open wounds from cookie-cutter sharks and scars typically looking like tag scars. However, no ID match has been made with tagged whales, so we are concerned that others may misinterpret such marks. No attempt was made to tag this animal.

In 3 cases bits of broken ears from the tags were seen in photographs taken at the time of tagging.

IMPACT/APPLICATIONS

Location only tags

ONR wanted the location only tags developed in collaboration with a manufacturer who would make them available to other researchers. The Spot-5 tags from WC cost ~$2000, about the same as the older Telonics ST-15 tags, but required little time for assembly of the attachments and penetrating tip (an additional ~$150) versus ~$1700 in additional materials and labor for the Telonics version. Wildlife Computers made the Spot-5 tags available to other users immediately. Some users applying tags at greater distances than us have experienced tag failures upon deployment. We typically deploy tags within 2-3 meters to control the tag’s position on the dorsum, vertical antenna orientation, and the striking angle of the tag. We typically use deployment pressures in the ARTS applicator for baleen whales of ~5 bar (~75 psi) with somewhat higher pressures (up to 8 bar – 120 psi) for sperm whales. Groups deploying tags from greater distances have used pressures up to 10 bars and photo-documented visible tag damage upon application. To avoid this, WC now casts these tags in a thicker-walled stainless steel tube for those users to compensate for larger acceleration and deceleration pressures associated with longer deployment distances.

To date, tag durations have been slightly better for Spot-5 tags vs the old style ST-15, however, we have experienced problems maintaining the user-programmed transmission schedule with the Spot-5 tag. The on-board data suggest this is an issue with the tag's saltwater switch (SWS), where the tag does not detect submergence and continues to transmit (at a 10 second interval) until the user-programmed limit of transmissions (250/day in our case) is reached. The transmission limit was thus often reached in the first 42 minutes of the first one-hour transmit period, so the transmitters did not transmit at other times of the day. A number of the tags with this problem were photographed with broken 'ears' (the stops to keep the tag from penetrating too far) meaning the tag had lost one or both of the washers used for the SWS. After discussing the issue with WC staff they suggested increasing the sensitivity of the SWS (reducing the threshold value) to counteract the reduced surface area for the switch when the ears break. Tags were re-programmed accordingly and a few were deployed before WC decided that the reduced threshold could cause other problems and it should be returned to the default value. Internal MMI discussions have concluded that moving the SWS to a stalked antenna (similar to the older Telonics tags) would solve the problem.

While the general style of attachments used on location-only tags deployed during recent field seasons has not changed, we have been working with university mechanical engineering students to test existing attachment methods and develop improved techniques. Testing is ongoing but initial results suggest using the existing petal design with thicker metal will improve attachment duration by making it harder to bend the barbs back if the tag is rubbed and starts to pull out. We have also experimented with memory metals that can be formed into shapes and revert to those forms after being distorted without loss of strength. Such atachments could be very effective, using temperature or electrical activation.

Advanced Dive Behavior Tag

The results of the GPS/TDR tags are very promising and the modification allowing them to be used up to three times means they qualify as "equipment", so no F&A (indirect cost) is charged for them, saving funds on future projects. The failure of the release mechanism in the 2011 deployments was addressed prior to the new generation we developed with Wildlife Computers and tested prior to deployments on sperm whales in 2013. While the issue was not entirely solved (two out of nine tags did not release from their housings and were lost), six of the tags functioned as programed and released for recovery. Tag recovery was successful but more challenging than expected. The distance from shore of the tags when they released during bad weather meant a significant amount of resources were required to charter a vessel large enough for the recovery mission. The distance also meant that a significant investment in time was required to reach and recover the tags. One tag that released but was not recovered was trapped in a gyre and rapidly carried beyond range of all but the largest vessels. Future tagging missions will need to consider this when planning recovery operations. The data from these tags has proven worthy of the added expense and effort for tag recovery by revealing wide-ranging movements and behavior over extended periods.

Recovery of the tags was meant to be facilitated by a real-time tracking system capable of receiving and decoding messages from the tag and using the gps locations in the messages to guide the vessel to the tag. The system worked very well during testing and for two early releases that occurred during the tag deployment work. Unfortunately, the system would not work during subsequent recovery missions on smaller vessels. A message received on Oct 31 from WC suggests that the problem has been traced to the Argos reciever used in the direction finding system. It appears that the reciever functions well at room temperature but as it gets hotter (approaching 30* C) it looses functionality. Ambient temperature in the Gulf of Mexico was easily over 30* C during the field work. The initial two

recoveries were likely successful because the reciever was set in the air conditioned bridge of the ship, while the smaller vessel used for the later recoveries did not have air conditioning. Further testing is needed to confirm these findings.

TRANSITIONS

The proof of concept was demonstrated for the lower cost LO casting technique and the utility of the easily changed attachments and penetration tips. Reviews by IWC and IUCN science panels approved the use of the 3-cell (longer version) tags on female Western gray whales for 2012 and resulted in a record-long track for gray whales. A WGW female's tag exceeded 400 days, which included a 23,000 km migration. While Wildlife Computers is already offering these LO tags as a mainstream product (fulfilling one ONR goals of this project), we are continuing to work with them to resolve problematic issues for ourselves and other users, especially SWS (saltwater switch design & sensitivity) and "stops" to avoid over-penetration.

The proof of concept demonstation for GPS/TDR tags during the DWH sperm whale project was impressive, and the release problems appear to have been significantly mitigated. The incorporation of Fasloc-3 technology added significant savings in energy consumption and the addition of magnetometers has allowed us to re-construct the movements of the whale while it was underwater. These data are important to identify and describe foraging and searching behavior by the whales. This kind of information will allow us to create better habitat models for sperm whales and to better understand how possible impacts to individuals may affect a larger group. There will likely be interest in understanding this for the impacts of sounds (sonar, seismic, ship noise, explosions, etc.).

The next step for the GPS/TDR tag is the development and inclusion of an acoustic dosimeter, which would be extremely useful in conjunction with the underwater behavioral (dive) data to determine ambient noise levels experienced by the whales and to identify what levels of sounds may affect "normal" behavior. Estimates of sound level could also be accomplished with sound propagation modeling and confirmed with calibrated recording buoys. Interest has been expressed by BOEM, oil & gas industry/JIP co-funders, NRDA trustees of the Deep Water Horizon oil spill, colleagues planning BRS projects in Australia with humpback whales using industry seismic sources, and NSF programs that use seismic data.

RELATED PROJECTS

We will be deploying more Spot-5 tags on fin whales during fall 2014 for a navy project to determine how often they transit Navy training areas in SOCAL, NWTT and Alaska. We will also continue to collect and analyze data from the six PCFG gray whales tagged this fall to learn more their habitats in the Pacific NW.

We will be approaching the NRDA trustees to conduct future BRS work on sperm whales and seismic survey sources in the GoM. We believe the Mk-10 tag data from multiple tagged whales in the same group of socially affiliated sperm whales can determine the volume of possible squid bait balls being worked by the group in a cohesive fashion. This technology will allow us to evaluate how consistent roles are in groups of foraging sperm whales, the way humpbacks seem to be during coordinated bubble-net feeding. We will also be able to determine if whales in the same affiliate group have the same relative response to variable prey densities (i.e.: they all have proportional increases or decreases in their foraging lunge rates as they move through different regions).

WORK PLAN

We will be analyzing data and writing papers, especially on the tag technologies we have developed under ONR sponsorship. We will also continue to develop analytical techniques for the very large files from the successful recent multi-week deployments of Advance Dive Behavior tags on sperm whales, especially including animations that bring multiple animals into the same frame in relation to their bathymetric environment. A partial list of papers expected from this effort includes:

* Assessing the current state of long duration satellite tracking: Where do we go from here?
* Migration of western gray whales to eastern north pacific breeding areas.
* Defining Pacific Coast Feeding Group gray whale habitat and distribution, including a pre-migration staging area
* Migratory timing and winter destination of Pacific Coast Feeding Group gray whales, the importance of offshore (non-lagoon) habitats to gray whales while in Mexican waters
* Assessing the potential impacts of tagging: wound healing of sperm and gray whales from implantable satellite tags across multiple years.
* Using a novel implantable Advanced Dive Behavior tag to compare the diving behavior of sperm whales in the Gulf of Mexico to the Gulf of California
* Sperm whale diving behavior as a proxy for patchy prey density and an explanation of movements over large spatial scales.
* Energetic requirements of sperm whales estimated from high resolution diving behavior
* Occurrence of sperm whales near active seismic survey vessels estimated from free-ranging tagged whales over long periods
* Evidence of distinct sub populations of Gulf of Mexico sperm whales based on bathymetric preferences, the onion skin concept.

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